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Restoration of Laramide right-lateral strike slip in northern New Mexico by using Proterozoic piercing points: Tectonic implications from the Proterozoic to the Cenozoic

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ABSTRACT

Early Proterozoic rocks in northern New Mexico can be used to document 100–170 km of right-lateral slip along a network of north-striking Laramide (Late Cretaceous–early Tertiary) faults that formed the precursor of the Rio Grande rift. Piercing lines are defined by the intersection of a subhorizontal 4 kbar isobaric surface with steeply dipping stratigraphic markers and regional structures. Restoration of slip provides new insight into the nature of Proterozoic orogenic and crustal province boundaries. The Yavapai crustal province (1.75–1.72 Ga juvenile volcanogenic rocks) is imbricated with overlying Hondo Group sedimentary cover in an originally east-trending ductile thrust belt that formed near the southern margin of the Yavapai province. A series of offset magnetic anomalies (Jemez lineament) is interpreted to mark the thrust-buried boundary between older (Yavapai province) and younger (Mazatzal province) crust. Our microplate tectonic model suggests that Laramide strike-slip movement (New Mexico) was kinematically linked with coeval extensional collapse (Arizona) and foreland shortening (Wyoming) during decoupling and northward movement of the rigid Colorado Plateau relative to the undeformed midcontinent. Crustal-scale strike-slip faults in New Mexico were reactivated during later Tertiary extension and continue to localize high heat flow in the Rio Grande rift and northward into Colorado.

INTRODUCTION

Data from Early Proterozoic rocks support and further constrain Chapin and Cather's (1981) model for a Laramide right-slip fault system in New Mexico. Chapin (1983) suggested ~100 km of slip on the basis of the realignment of northeast-trending magnetic anomalies. Our proposed restoration of 100–170 km of slip provides a testable model for the location and magnitude of individual faults of this system. Restoration of Phanerozoic deformation provides insights into the regional structure of Proterozoic basement rocks of the southwest United States and helps constrain a model involving coeval extension, strike slip, and shortening associated with northward movement of a rigid Colorado Plateau block during Late Cretaceous–early Tertiary time.

RESTORATION OF PROTEROZOIC ROCKS IN NEW MEXICO

Early Proterozoic–age rocks are exposed in isolated mountain uplifts in northern New Mexico and southern Colorado (Fig. 1). Both lithostratigraphic (Bauer and Williams, 1989) and terrane (Grambling et al., 1988) subdivisions emphasize the similarities of rock packages in adjacent ranges. This paper extends the hypothesis of Miller et al. (1963), that Proterozoic rocks and structures can be directly correlated from range to range. The strongest evidence for kilometre-scale strike-slip offsets of Proterozoic rocks and structures comes from the Rio Mora, Truchas, Picuris, and Tusas uplifts, which we propose were once part of a continuous Proterozoic thrust belt (inset in Fig. 1). This proposed alignment is based on correlation of stratigraphic markers, alignment of major thrusts and folds, and similarity of metamorphic grade, as discussed below.

Stratigraphic correlations are based on the distinctive Vadito and Hondo groups. These rocks overlie 1.75–1.72 Ga mafic metavolcanic rocks and associated granodiorite plutons that form the heterogeneous arc-related crust of the southwest United States (Karlstrom and Bowring, 1993). The Vadito Group (1.7 Ga) is dominated by felsic metavolcanic rocks, with a distinctive Mn-rich layer (1–50 m thick) at its top (perhaps a paleosol) that is characterized by Mn-andalusite, piemontite, and other Mn-rich minerals (Grambling and Wiliams, 1985). This layer can be matched from range to range (Fig. 1). The overlying Hondo Group is dominated by the 1-km-thick Al-rich Ortega quartzite that also correlates from range to range. This quartzite is interpreted as a shallow marine "shelf" sequence derived from the north (Soegaard and Erikson, 1986). The Uncompahgre Formation of the Needle Mountains is similar in thickness and lithology to the Hondo Group and also contains Mn-andalusite (Burns et al., 1980). Major structures also correlate between uplifts. Each range contains two major Proterozoic thrusts (e.g., the Plomo and Pilar faults of the Picuris Mountains; Bauer, 1993) that bound the southernmost of a series of kilometre-scale overturned synclines involving the Hondo Group (Fig. 1; La Madera syncline in the Tusas Mountains; Williams, 1991a; Hondo syncline in the Picuris Mountains, Bauer, 1993).

Direct strike-slip realignment of stratigraphic sequences and structures (Fig. 1) is possible because each range was at about the same crustal depth (12 ±2 km) after Proterozoic deformation. Metamorphic isograds in New Mexico are subhorizontal and overprint map-scale folds and faults, indicating that metamorphism outlasted or postdated shortening (Grambling et al., 1989). Metamorphic pressure-temperature estimates (Grambling et al., 1989) indicate conditions of 525 ±25 °C and 3.8–4.5 kbar in each of the ranges. The timing of metamorphism remains controversial (Williams, 1991b), but is bracketed between 1.65 and 1.4 Ga. Thus, the intersection of regionally subhorizontal isobaric surfaces with preexisting subvertical markers and structures creates regional piercing lines that can be used to restore the net (post–1.4 Ga) displacement. This restoration suggests that postmetamorphic vertical displacement and tilting between ranges was insignificant relative to the strike-slip displacement.

A band of northeast-trending magnetic highs (Zietz, 1982) also shows right-lateral offset across north-striking faults (Fig. 1). This band corresponds to the Jemez lineament, an alignment of Cenozoic volcanic centers (Aldrich et al., 1986). The north edge of this zone (Fig. 1) coincides with the southernmost outcrops of Yavapai volcanogenic basement (>1.7 Ga) and Hondo Group cover and the northernmost limit of 1.65 Ga supracrustal rocks. Thus, as in Arizona, the Jemez lineament appears to mark a crustal province boundary.

DISCUSSION OF RIGHT-SLIP FAULTS

Proterozoic exposures in New Mexico are bounded by high-angle faults with complicated movement histories. Our estimates of right-lateral offset since 1.4 Ga include ~80 km of slip across the

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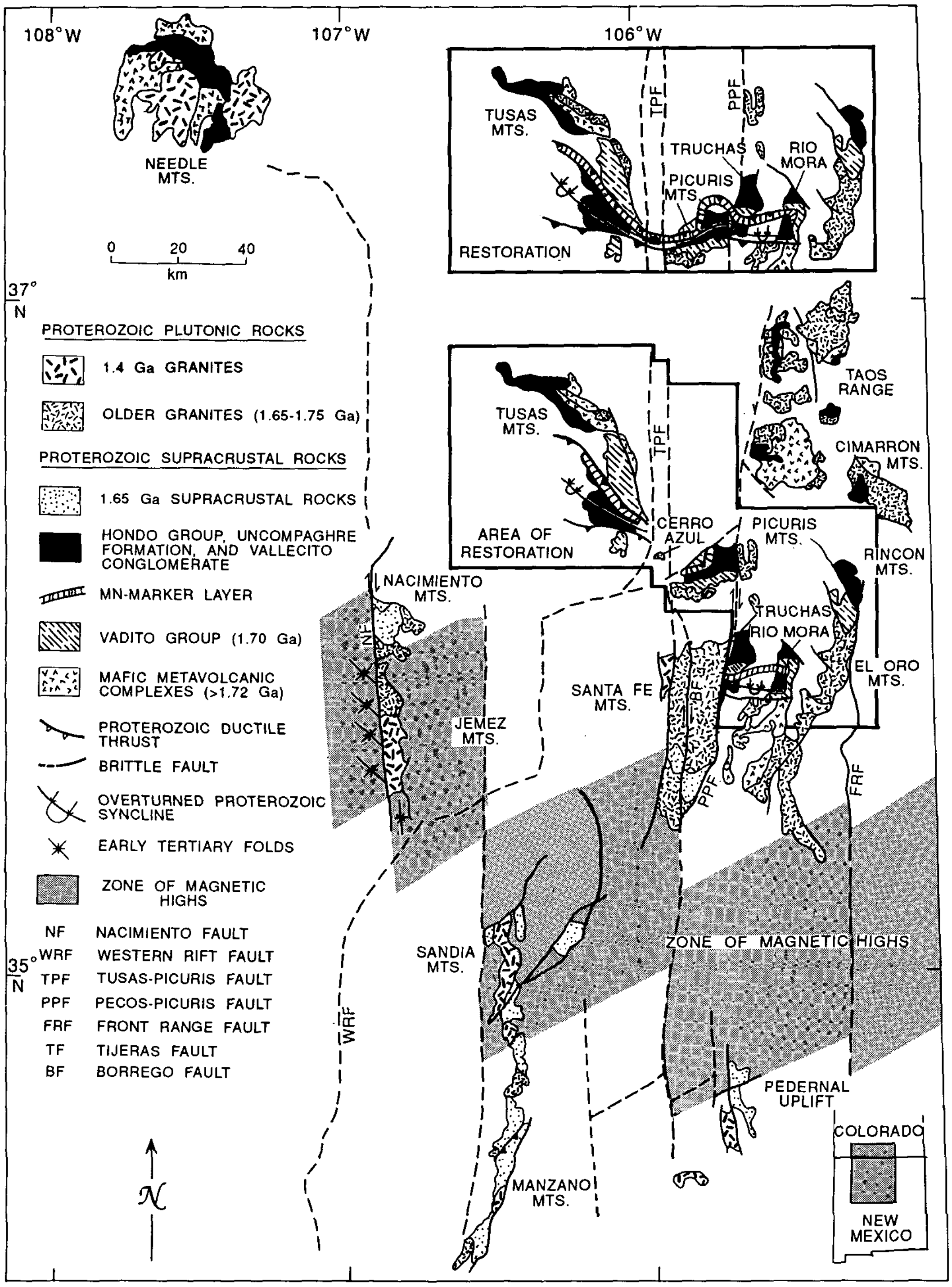

Figure 1. Proterozoic rocks of northern New Mexico and southern Colorado. Major range-bounding faults with inferred Late Cretaceous–early Tertiary right slip are shown. Inset shows proposed realignment of Proterozoic rocks in Tusas, Cerro Azul, Picuris, Truchas, and Rio Mora uplifts.

Nacimiento and western rift faults, 15 km across the Tusas-Picuris fault, 37 km across the Picuris-Pecos fault (Miller et al., 1963), and several to tens of kilometres across the Front Range faults (Fig. 1). The best determination for the amount of strike-slip displacement (~50 km) is from the Tusas Mountains east to the Rio Mora uplift (inset in Fig. 1). In addition, Baltz (1967) mapped a series of en echelon folds in Mesozoic and early Tertiary strata west of the Nacimiento fault and estimated ~5 km of Eocene right slip. However, we add 70–80 km of right slip on both this and a concealed western rift fault to accommodate the suggestion by Laughlin (1991) that the Sandia Granite "correlates" with the Fenton Hill granodiorite encountered in drill holes beneath the Jemez Mountains some 80 km north of the Sandia Mountains and to match up the offset magnetic anomalies. Front Range faults show a dextral component, but the magnitude of slip is not well known (Baltz and O'Neill, 1980).

Timing of movement(s) on these faults is not well constrained and probably involved various combinations of late Paleozoic, Laramide, and late Tertiary slip. Miller et al. (1963) also postulated a Precambrian ancestry for the Picuris-Pecos fault on the basis of ductile rotation of foliation into the fault. However, our observations are that both the Picuris-Pecos and Borrego faults are brittle strike-slip features that abruptly truncate Proterozoic foliations. Pennsylvanian movement was dominantly dip-slip (Miller et al., 1963; Soegaard, 1990), as was late Tertiary slip. Thus, following Chapin and

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Cather (1981) we propose that most of the right-lateral strike-slip occurred in the Laramide.

IMPLICATIONS FOR PROTEROZOIC CRUSTAL PROVINCES

Controversy regarding the nature and location of both Proterozoic crustal province boundaries and Proterozoic orogenic belts (Karlstrom and Bowring, 1993) is clarified by the realignment of Proterozoic rocks and structures in northern New Mexico (Fig. 2). As in most orogens, deformational provinces do not correspond to crustal provinces, because deformation is transmitted far inboard of the margins of colliding terranes. Our reconstruction (Fig. 3) shows a major zone of tectonic imbrication of Yavapai province basement (>1.7 Ga), Hondo Group cover (1.7 Ga) and Mazatzal province (~1.65 Ga) crust in northern New Mexico and southern Colorado. The northern part of this belt (the Mazatzal thrust belt) shows thrust and fold geometries (Williams, 1991a) similar to foreland thrust belts and marks the zone of exposure of thick quartzite successions. It is interpreted to record deformation of the Yavapai province foreland due to the 1.65 Ga collision of the Mazatazal province. A thrust buried crustal province boundary marking the southern limit of known Yavapai crust and the northern limit of 1.65 Ga supracrustal rocks appears to correspond with the northern boundary of the Jemez lineament (Figs. 2 and 3).

The east trend of the reconstructed Mazatzal thrust belt in New Mexico is a departure from the northeast trend of tectonic boundaries in Arizona. This bend in the thrust belt may reflect the geometry of the southern continental margin of 1.7 Ga Laurentia (Fig. 3). Such a plate margin configuration may help explain variations in the style and intensity of 1.65 Ga deformation. The 1.7 Ga craton margin in northern New Mexico may have been a salient and thus more intensely deformed, overthickened, and subsequently uplifted by a colliding Mazatzal province. This is compatible with the higher pressure of early Proterozoic–age rocks in New Mexico (4 kbar; Grambling et al., 1989) vs. Arizona (3 kbar; Williams, 1991b) and the wide zone of 1.65 Ga deformation in New Mexico and Colorado.

IMPLICATIONS FOR LARAMIDE MICROPLATE TECTONICS

Our model (Fig. 3) suggests that 100–170 km of Laramide right slip in New Mexico accommodated the northward translation of the relatively rigid Colorado Plateau. Although the details differ, we follow Hamilton (1981) and Chapin and Cather (1981) in trying to link displacements around the Plateau into a kinematically balanced microplate tectonic framework. The linkage between strike slip in New Mexico and Colorado and Laramide foreland shortening in Wyo-

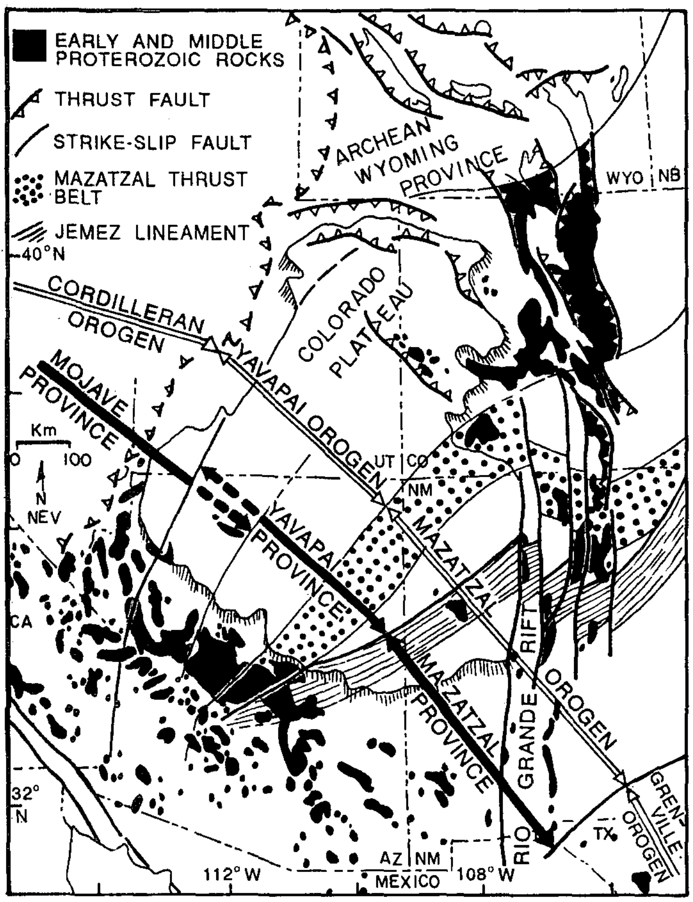

Figure 2. Proterozoic rocks of southwest United States and proposed Proterozoic boundaries. Crustal provinces represent blocks of distinct age and composition: Mojave (Archean component), Yavapai (1.75–1.70 Ga juvenile crust), and Mazatzal (1.66–1.60 Ga juvenile crust). Orogens are defined on basis of deformational fronts: Cordilleran orogen (Mesozoic thrusting), Yavapai orogen (1.74–1.69 Ga deformation), Mazatzal orogen (1.65–1.60 Ga deformation), and Grenville orogen (1.3–1.0 Ga deformation).

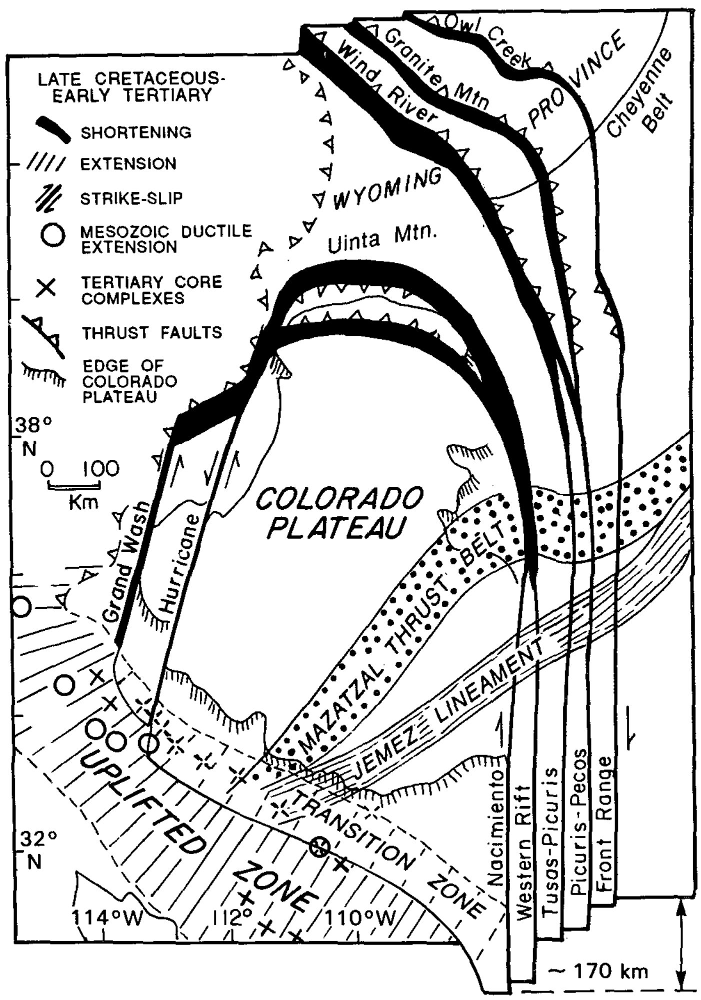

Figure 3. Restoration of Colorado Plateau to its inferred Late Cretaceous position, and kinematic framework of Late Cretaceous–early Tertiary deformation. From 100 to 170 km of northward movement of rigid Colorado Plateau (and Arizona transition zone) produced foreland shortening (Wyoming, Utah, Colorado), strike-slip (New Mexico and western Arizona), and gravitationally induced orogenic collapse (Arizona-Sonora).

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ming seems likely because of the continuity of regional fault systems. The timing of movement (Late Cretaceous–early Tertiary) and amount of shortening (~100 km; Gries, 1983) across Wyoming may be comparable to the proposed right slip in New Mexico. The predicted Laramide extension in southern Arizona and left slip (and shortening) across the Hurricane, Grand Wash, and Lemington faults on the western edge of the Colorado Plateau (Fig. 3) are more speculative because of intense late Tertiary deformational overprints. However, there is increasing evidence for Mesozoic–early Tertiary mid-crustal extension in southern California (Foster et al., 1992; Hodges and Walker, 1992) and Arizona (Livaccari, 1991) and for a Laramide ancestry for major structures in the western Colorado Plateau.

The dynamic framework for the northward translation of the plateau is speculative. Our restoration (Fig. 3) shows the Colorado Plateau and Arizona's transition zone structurally above the Tertiary core complexes in the Late Cretaceous. This is compatible with a proposed zone of overthickened crust in southern Arizona (Coney and Harms, 1984; Gastil et al., 1992). Although lower plates of core complexes were finally exhumed to upper crustal levels, and reversal of drainage from northward to southward in central Arizona (Gastil et al., 1992) took place in the middle to late Tertiary, our model follows Livaccari (1991) in suggesting that some (perhaps substantial) fraction of extensional thinning of the orogen also took place in the Laramide. This model is broadly analogous to the gravitational collapse of high topography in the Himalayas and the northward translation of the Tibetan Plateau (Hodges et al., 1992). Late Cenozoic tectonics of the southwest United States were profoundly influenced by this Laramide history in that mid-Tertiary extension in the core complexes was superimposed on crust that had undergone an interplay of contraction and extension in the Late Cretaceous–early Tertiary. Further, the Rio Grande rift (and perhaps the Colorado River corridor) was localized along earlier faults. The Rio Grande rift structures continue to localize high heat flow in a north-trending zone in New Mexico and Colorado (Decker et al., 1988).

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